Abstract #268081

AQUEOUS ALTERATION ON MARS: EVIDENCE FROM LANDED MISSIONS

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Mineralogical and geochemical data returned by orbiters and landers over the past 15 years have substantially enhanced our understanding of the history of aqueous alteration on Mars. Here, we summarize aqueous processes that have been implied from data collected by landed missions. Mars is a basaltic planet. The geochemistry of most materials has not been "extensively" altered by open-system aqueous processes and have average Mars crustal compositions. There are few examples of open-system alteration, such as Gale crater's Pahrump Hills mudstone. Types of aqueous alteration include (1) acid-sulfate and (2) hydrolytic (circum-neutral/alkaline pH) with varying water to rock ratios. Several hypotheses have been suggested for acid-sulfate alteration including (1) oxidative weathering of ultramafic igneous rocks containing sulfides, (2) sulfuric acid weathering of basaltic materials, (3) acid fog weathering of basaltic materials, and (4) near-neutral pH subsurface solutions rich in Fe^{2+} that rapidly oxidized to Fe^{3+} producing excess acidity. Meridiani Planum's sulfate-rich sedimentary deposit containing jarosite is the most "famous" acid-sulfate environment visited on Mars, although ferric sulfate-rich soils are common in Gusev crater's Columbia Hills and jarosite was recently discovered in the Pahrump Hills. An example of aqueous alteration under circum-neutral pH conditions is the formation of Fe-saponite with magnetite *in situ* via aqueous alteration of olivine in Gale crater's Sheepbed mudstone. Circum-neutral pH, hydrothermal conditions were likely required for the formation of Mg-Fe carbonate in the Columbia Hills. Diagenetic features (e.g., spherules, fracture filled veins) indicate multiple episodes of aqueous alteration/diagenesis in most sedimentary deposits. However, low water-to-rock ratios are prominent at most sites visited by landed missions (e.g., limited water for reaction to form crystalline phases possibly resulting in large amounts of short-range ordered materials and little physical separation of primary and secondary materials). Most of the aqueous alteration appears to have occurred early in the planet's history; however, minor aqueous alteration may be occurring at the surface today (*e.g.*, thin films of water forming carbonates akin to those discovered by Phoenix).
Abstract ID#:
268081
Password:
861649
Meeting:
2015 GSA Annual Meeting in Baltimore, Maryland, USA (1-4 November 2015)
Session Type:
Topical Session
Primary Selection:
T177. When Water Meets Rock: Aqueous Alteration in the Solar System

Abstract Title:
AQUEOUS ALTERATION ON MARS: EVIDENCE FROM LANDED MISSIONS
Preferred Presentation Format:
Oral
Discipline Categories:
Geochemistry Mineralogy/Crystallography Planetary Geology
Abstract Submission Fee:
Paid (gsa-2015AM-9870-3237-6511-2339)
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